

CLINICAL COMMENTARY
POSTACTIVATION POTENTIATION:
AN INTRODUCTION

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ABSTRACT

Improving strength and power in the athlete who is being rehabilitated is a central focus of the sports physical therapist, particularly in the terminal phases of rehabilitation where the emphasis shifts to readiness to return to sport and sports performance enhancement. High load strength training and power training through plyometric exercises are two key components of performance enhancement programs. A current concept in the strength and conditioning literature that is relatively unknown in sports physical therapy is postactivation potentiation (PAP). Even though we have limited data and there may be limited application of the concept of PAP for the sports physical therapist, awareness of this phenomenon is important nonetheless. The purpose of this clinical commentary is to introduce the sports physical therapist to the concept of PAP.

Key Words: complex training, power training, postactivation potentiation, strength training

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INTRODUCTION

In the terminal phases of rehabilitation, the focus of rehabilitation tends to shift from restoration of impairments and functional limitations to return to sport and improving athletic performance. Once effusion has been minimized or eliminated, range of motion and strength have been restored, and the athlete has successfully completed a functional progression, specific return to sport activities commence in order to maximize performance potential. Prior to unrestricted participation in sports, improvements in an athlete's strength, power, and speed are common goals for the sports physical therapist which are important to address in the rehabilitation plan. During this stage, there is often collaborative effort between strength and conditioning staff as well as the athletic training staff due to the transition from a mindset of rehabilitation to that of return to sport and sport-specific performance. Therefore, it is imperative that the sports physical therapist be familiar with terms and training methodologies that may be implemented during this stage of rehabilitation.

Several methods exist to increase strength and power in the athlete. Strength is the ability of the muscle to exert force or torque at a specified or determined velocity,¹ while power is defined as work per unit of time (force times distance divided by time) or as force times velocity (distance x time).¹ Traditional weight training with relatively heavy loads (80-90% of 1 RM) for relatively few repetitions (4-8 repetitions) has shown the ability to improve an athlete's strength and is reported to enhance power to a greater extent than light loads.^{2,3} Plyometric training alone has been advocated as a means to improve muscular power and rate of force development (RFD) as compared to traditional weight training techniques, leading to improvements in dynamic athletic performance such as sprinting and jumping. Advocates have stated that plyometrics are a potential method used to bridge the gap between strength and power training methods.⁴ Rate of force development is the rate at which strength increases, or the rate at which force can be produced.⁵ RFD is the single most important neural adaptation for the majority of athletes.⁶ Training programs dedicated to the development of power require both high-force training and high-quality power movements in which time and the rapidity of movements play a vital role in the quality of the exercise.⁷

Recently, a concept known as *post-activation potentiation* (PAP) has surfaced as a means to maximize acute power development in athletes. While it is not known yet at this time if there are any positive affects other than an acute increase in power, if the concept is more appropriate than using plyometrics alone, or if it has any application in sports rehabilitation, it is nonetheless important that the sports physical therapist be familiar with the term as well as the concept behind its application. The purpose of this commentary is to introduce the reader to the PAP concept which is common in strength and conditioning literature, but a likely unknown in sports physical therapy. Given that the sports physical therapist is often actively involved in the long-term training regimens of athletes, an understanding of the concept is warranted.

POST-ACTIVATION POTENTIATION

Originally defined by Robbins,⁸ PAP is a phenomenon by which the force exerted by a muscle is increased due to its previous contraction. Post-activation potentiation is a theory that purports that the contractile history of a muscle influences the mechanical performance of subsequent muscle contractions. Fatiguing muscle contractions impair muscle performance, but non-fatiguing muscle contractions at high loads with a brief duration may enhance muscle performance.⁹ The peak torque of an isometric twitch in skeletal muscle is transiently increased after a brief maximum voluntary contraction.^{10,11} Thus, PAP is the increase in muscle force and rate of force development (RFD) that occurs as a result of previous activation of the muscle,^{12,13} as well as the force and power of evoked high velocity shortening contractions, and the maximum velocity attained by evoked shortening contractions under load. In other words, excitation of the nervous system produces an increase in contractile function due to a heavy load conditioning stimulus.¹⁴ The most common indicator of PAP is increased evoked isometric twitch force observed following an evoked isometric tetanic contraction.¹²

PAP is typically induced from maximum voluntary contractions, but has also been induced by velocity-controlled maximal voluntary concentric and eccentric contractions, as well as induced by submaximal isometric contractions.¹² In a set of weightlifting exercises, the alternating submaximal concentric

and eccentric contractions may induce PAP, but the presence and extent of PAP produced by weight lifting exercise has not been determined.¹²

There are two proposed mechanisms of PAP. The first is the phosphorylation of myosin regulatory light chains, which renders actin-myosin more sensitive to calcium released from the sarcoplasmic reticulum during subsequent muscle contractions.^{13,15-17} As a result, the force of each successive twitch contraction is increased. The second is that strength training prior to plyometric exercises causes increased synaptic excitation within the spinal cord, which in turn results in increased post-synaptic potentials and subsequent increased force generating capacity of the involved muscle groups.¹⁸ The most important muscle characteristic affecting the magnitude of PAP is fiber type, with the greatest potential for enhanced PAP in muscles with the highest proportion of Type II fibers.^{15,19,20} Further, PAP is greater in muscles with the shortest twitch contraction time.^{17,19,21,22} Based on muscle fiber type, athletes who perform in maximal intensity activities that depend on Type II muscle fibers (i.e. sprinting, weightlifting, throwing, jumping) would also show the greatest PAP in muscles involved in their sports performance.²³

A method that the sports physical therapist can use to implement the concept of PAP for potential acute increases in power is through utilization of complex training. *Complex training* alternates biomechanically similar high-load weight training with plyometric exercises, set for set, in the same workout.²⁴ Essentially, complex training involves pairing a high force activity with a high power activity. For example, the athlete may perform a high-load back squat followed by a countermovement jump or box jumps.

There is evidence supporting the utilization of complex training,²⁵⁻²⁷ although there is also evidence suggesting otherwise.²⁹ At this time however, to the author's knowledge, there are no studies utilizing complex training in rehabilitation, nor is the scientific community certain that complex training impacts PAP or if it is simply a natural, acute phenomenon in the muscle. Sale has argued that PAP is more of a muscle phenomenon than something that can be trained or altered. It may be something that is simply an observation rather than something that can be

used in training of an athlete.¹¹ Previous studies using PAP have been performed on healthy, trained athletes. Comyns et al²⁵ found that repeated exposure to complex training improved sprint performance in uninjured rugby players. Santos and Janiera²⁸ found that complex training significantly improved squat jump, countermovement jump, medicine ball throw, and the Abalakov agility test (a 4x10-m agility test and a maximal vertical jump test) in young, uninjured male basketball players. Low- and high-load complex training was investigated by Matthews and others²⁶ in basketball players' ability to perform a push-pass. Authors of the study suggest that high loads are needed to elicit a potentiation effect, and therefore loads nearing 85% of 1RM should be used to facilitate short-term power increases.²⁶

A more recent study by Mitchell and Sale¹² sought to determine if weight lifting induces PAP, indicated as potentiation of muscle twitch force. Researchers tested whether a five-repetition maximum (5-RM squat) both induced PAP and increased height of subsequently performed counter-movement jumps (CMJ). Subjects did five sets of CMJ both before and four minutes after one set of barbell back squats done with a 5-RM. Researchers observed a 2.9% increase in CMJ height four minutes after a 5-RM squat. This increase in CMJ was a significant enhancement of jump performance. These authors were the first to test the assumption that a weight lifting exercise induces PAP. Ultimately, the researchers concluded that PAP may have contributed to the increase in CMJ height, but the correlation between the magnitude of PAP and the percentage increase in CMJ height was not significant.

DISCUSSION

Clearly, much more information is needed on the concept of PAP before definitive conclusions can be made about its application as an actual training method or if it is simply a muscle phenomenon that causes an acute increase in power. More importantly, it is not known if it is appropriate for the recovering athlete due to the high loads used in both the high-load strength exercise as well as in the high-intensity plyometric exercises. The challenge for the sports physical therapist is to safely and effectively determine the load to use to utilize this concept appropriately. One-repetition maximum (1 RM) or a percentage of 1 RM is

often used as the standard upon which to base the load used in strength and conditioning programs and literature, however, this 1 RM is being determined in healthy athletes. It is generally accepted that determining 1 RM in a recovering athlete is contraindicated because maximal efforts may cause a deleterious effect on healing or lead to further injury. Therefore, estimates of 1 RM or a 6 RM may be more appropriate. Several methods exist to potentially help the sports physical therapist provide adequate stimulus to obtain a PAP effect. The DeLorme technique,²⁹ the Daily Adjusted Progressive Resistance Exercise (DAPRE),³⁰ and the Oddvar Holten Diagram³¹ exist to provide a structured method to estimate load without performing a 1 RM. Furthermore, because the loads tend to be greater than 85% of 1 RM with the use of Olympic lifting bars or machines, equipment availability can also be a concern for the sports physical therapist. Olympic lifting requires Olympic bars, bumper plates, and extra space and resources that may not be available or in the budget. Furthermore, there is a tremendous learning curve with these movements.

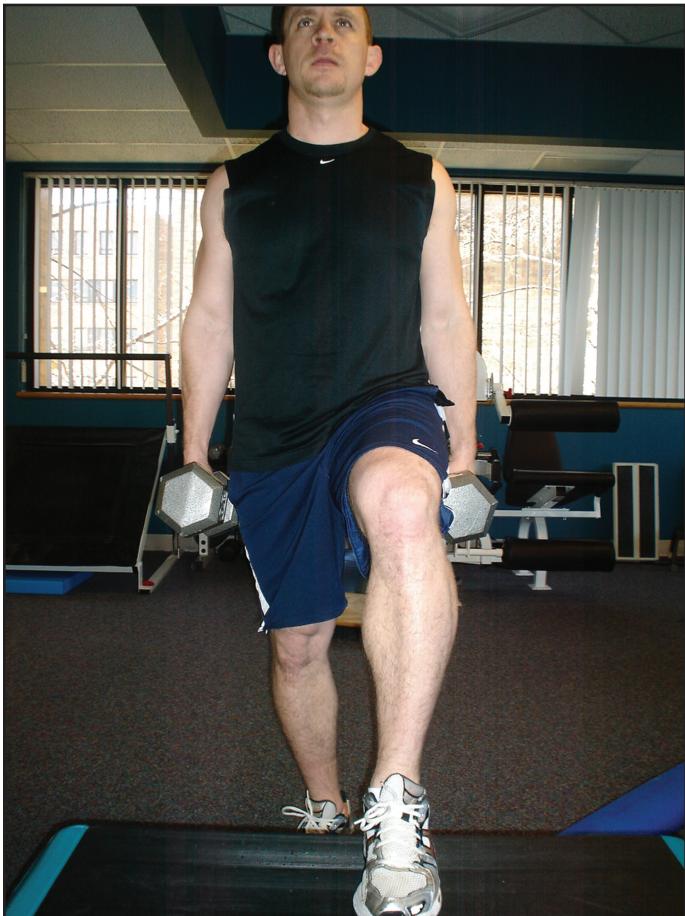


Figure 1. High load step ups.

For the sports physical therapist training the recovering athlete, the PAP concept may be most appropriately applied during functional training. The sports physical therapist could consider performing high-load leg presses early in a training session and then perform plyometric training exercises towards the end of the session in order to attempt to utilize the PAP concept. One could also use high load resistance activities prior to performing functional testing, in order to maximize performance in such tests as the single leg hop for distance, triple jump, 6 M timed hop, or vertical jump testing. However, it is not known if the short-term effects are carried over to future training sessions or if there is a long-term benefit. Plus, if short-term benefits were obtained from using the concept of PAP during functional testing, the sports physical therapist may not gain an accurate assessment of current status. Again, at this time, the above information is purely speculative.

If the sports physical therapist were to utilize this concept clinically, one possibility may be in helping to



Figure 2. Walking lunges with dumbbells.



Figure 3. Single leg dumbbell squat.

facilitate acute power increases in a unilateral lower extremity injury. Assuming a unilateral lower extremity condition (i.e. status post ACL reconstruction), the sports physical therapist may have the athlete perform exercises such as high-load step ups (Figure 1), walking lunges with dumbbells (Figure 2), single leg dumbbell squats (Figure 3), or utilize the single-leg press. These may be advocated over back squats or front squats because they enable the athlete to have unilateral emphasis to assist in the attempt to equalize strength among the extremities. Neitzel et al³² revealed that it can take several months after an ACL reconstruction to distribute weight evenly on both feet. Lunges, step ups, and single leg press may help mitigate the decrease in weight-bearing that may exist on the involved limb. To maximize strength, no more than 4-8 repetitions should be performed.^{2,3} Following the strength exercise, the athlete may then perform split jumps (Figure 4), box jumps, single leg counter-movement jumps from a step or box (Figure 5), or single leg vertical jumps (Figure 6) for up to 6 repetitions.

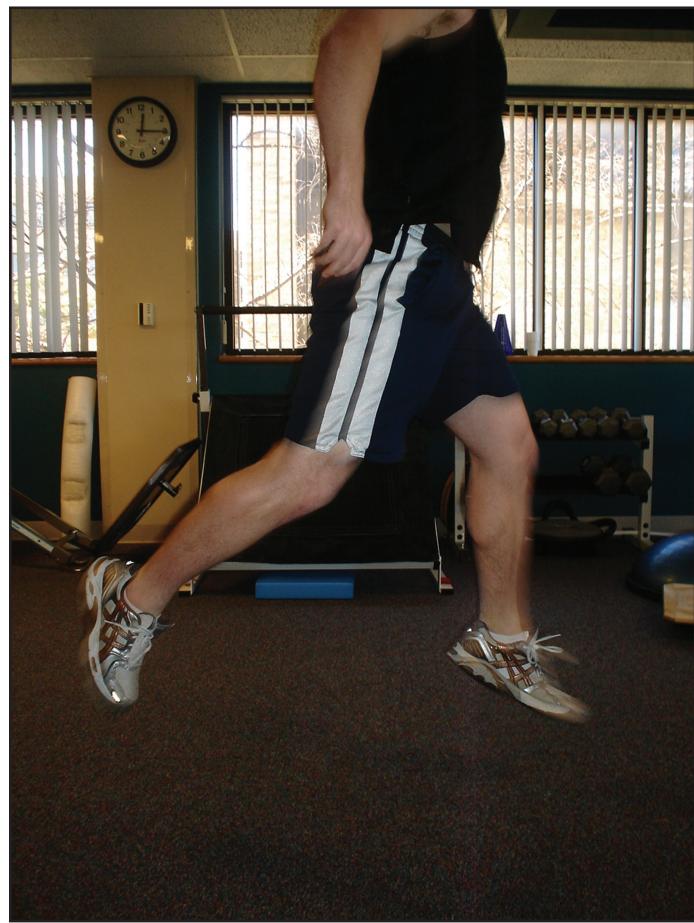


Figure 4. Split jumps.

Although based entirely on author opinion, resistance should begin with body weight to ensure appropriate technique is maintained and that the athlete has no subsequent effusion or pain. Based on studies using the concept of PAP, it is not currently advocated to perform the plyometric exercise with an external load. At this time, the author cannot support or repudiate this approach. Intuitively, in the rehabilitating athlete, bodyweight is most appropriate to limit risk of further injury and to ensure proper mechanics.

Rest periods between the strength exercise and the plyometric exercise in the available literature have been the topic of debate, but it appears that most benefit is obtained when at least an 8-12 minute rest period is completed prior to the plyometric exercise when performing it in a complex training format.³³ A prolonged rest period with no activity is not practical for the sports physical therapist in most settings, and performing explosive exercises in a state of fatigue may impair performance.³⁴



Figure 5. Countermovement from step.

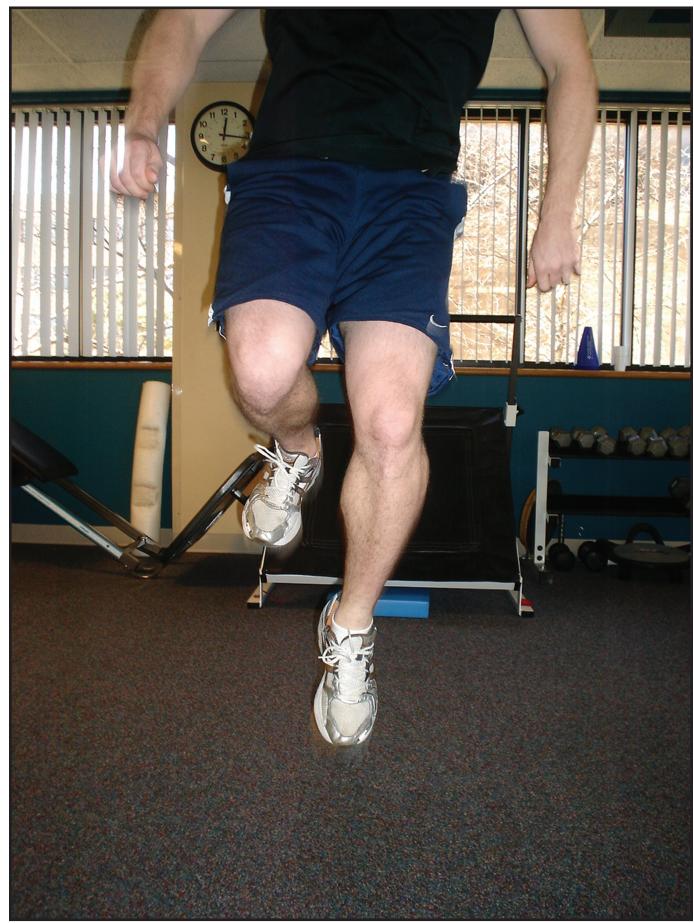


Figure 6. Single leg vertical jump.

Resistance Exercise	Biomechanically-Similar Plyometric Activity	Rest Period (between resistance exercise and plyometric exercise)
Single Leg Press 4 x 6-8	Single Leg Vertical Jump 4 x 3 each leg	4-8 minutes, based on load or %RM
Walking Lunges 4 x 6 each	Split Jumps 4 x 3 each leg	4-8 minutes, based on load or %RM
DB Step Ups 3 x 6-8 each leg	Single Leg Countermovement Jump 3 x 3 each	4-8 minutes, based on load or %RM

The reader is referred to Table 1 for a sample workout utilizing PAP. It should be noted that both the table and the above suggestions are purely speculative. Note that resistance load (% RM) is not given and must be determined for each athlete. Clearly, further research is warranted in this area, particularly in the recovering athlete. Future research should determine appropriate rest periods between the strength and plyometric exercises, the appropriate load, and whether or not training history affects these variables.

CONCLUSIONS

Increasing strength and power production is a common goal for sports physical therapists. Postactivation potentiation is one of many concepts that exist that have shown promise in healthy, trained athletes to help improve acute increases in strength and power, although at this time, its application for the rehabilitating athlete is limited. Additionally, it is not known yet whether or not prolonged effects are realized or if it is purely an acute phenomenon. Although more research is needed both on healthy and recovering athletes, it is important that the sports physical therapist be cognizant of this unique training methodology in order to potentially provide optimum stimuli for return to athletic performance.

REFERENCES:

1. Knutgen HG, Kraemer WJ: Terminology and measurement in exercise performance. *J Appl Sport Sci Res*. 1987;1:1-10.
2. Schmidtbileicher D, Buerkle M. Neuronal adaptations and increase of cross-sectional area studying

- different strength training methods. In: *Biomechanics X-B*, Vol. 6-B. Johnson GB, ed. Champaign, IL: Human Kinetics, 1987. 615-620.
3. Schmidbleicher D, Harlambie G. Changes in contractile properties of muscle after strength training in man. *Eur J Appl Physiol*. 1981; 46: 221-228.
 4. Chu D. *Jumping into Plyometrics*. Champaign, IL: Leisure Press, 1992. 1-4.
 5. Siff MC, Verkoshansky YV. *Supertraining*. Denver, CO: Supertraining International, 4th ed. 1999.
 6. Clark MA: *Integrated Training for the New Millennium*, Thousand Oaks, CA, 2001, National Academy of Sports Medicine.
 7. Fleck SJ, Kraemer WJ: *Designing Resistance Training Programs*, ed 3, Champaign, IL, 2004, Human Kinetics.
 8. Robbins DW. Postactivation potentiation and its practical applicability: a brief review. *J Strength Cond Res*. 2005; 19: 453-458.
 9. Stone MH, Sands W, Pierce K, et al. Power and power potentiation among weightlifters: preliminary study. *Int J Sports Physiol Perform*. 2008; 3: 55-67.
 10. Hodgson M, Docherty D, Robbins D. Postactivation potentiation: Underlying physiology and implications for motor performance. *Sports Med*. 2005; 35: 585-595.
 11. Sale DG. Postactivation potentiation: role in human performance. *Exerc Sport Sci Rev*. 2002; 30: 138-143.
 12. Mitchell CJ, Sale DG. Enhancement of jump performance after a 5-RM squat is associated with postactivation potentiation. *Eur J Appl Physiol*. 2011. Epub ahead of print 1/13/2011.
 13. Judge LW. The application of postactivation potentiation to the track and field thrower. *Strength Cond J*. 2009; 31(3): 34-36.
 14. Rixon KP, Lamont HS, Bemben M. Influence of type of muscle contraction, gender, and lifting experience on postactivation potentiation performance. *J Strength Cond Res*. 2007; 21: 500-505.
 15. Grange RW, Vandenboom R, Houston ME. Physiological significance of myosin phosphorylation in skeletal muscle. *Can J Appl Physiol*. 1993; 18: 229-242.
 16. Sweeney HL, Bowman BF, Stull JT. Myosin light chain phosphorylation in vertebrate striated muscle: regulation and function. *Am J Physiol*. 1993; 264: C1085-C1095.
 17. Vandenboom R, Grange RW, Houston ME. Myosin phosphorylation enhances rate of force development in fast-twitch skeletal muscle. *Am J Physiol*. 1995; 268: C596-C603.
 18. Rassier DE, Herzog W. Force enhancement following an active stretch in skeletal muscle. *J Electromyogr Kinesiol*. 2002; 12(6): 471-477.
 19. Hamada T, Sale DG, Macdougall JD, Tarnopolsky MA. Postactivation potentiation time in human knee extensor muscles. *J Appl Physiol*. 2000; 88: 2131-2137.
 20. Young W, Mclean B, Ardagna J. Relationship between strength qualities and sprinting performance. *J Sports Med Phys Fitness*. 1995; 35: 13-19.
 21. Gordon DA, Enoka RM, Stuart DG. Motor-force potentiation in adult cats during a standard fatigue test. *J Physiol*. 1990; 421: 569-582.
 22. Vandenboom R, Grange RW, Houston ME. Threshold for force potentiation associated with skeletal myosin phosphorylation. *Am J Physiol Cell Physiol*. 1993; 265: C1456-C1462.
 23. Requena B, De Villareal SS, Gapeyeva H, et al. Relationship between postactivation potentiation of knee extensor muscles, sprinting, and vertical jumping performance in professional soccer players. *J Strength Cond Res*. 2011; 25: 367-373.
 24. Alves JM, Rebelo AN, Abrantes C, Sampaio J. Short-term effects of complex and contrast training in soccer players vertical jump, sprint and agility abilities. *J Strength Cond Res*. 2010; 24(4): 936-941.
 25. Comyns TM, Harrison AJ, Hennessy LK. Effect of squatting on sprinting performance and repeated exposure to complex training in male rugby players. *J Strength Cond Res*. 2010; 24(3): 610-618.
 26. Matthews M, O'Conchuir C, Comfort P. The acute effects of heavy and light resistances on the flight time of a basketball push-pass during upper body complex training. *J Strength Cond Res*. 2009; 23(7): 1988-1995.
 27. Santos EJ, Janeira MA. Effects of complex training on explosive strength in adolescent male basketball players. *J Strength Cond Res*. 2008; 22(3): 903-909.
 28. Hopper DM, Hopper JL, Elliott BC. Do selected kinanthropometric and performance variables predict injuries in female netball players? *J Sports Sci*. 1995; 13(3): 213-222.
 29. DeLorme TL. Restoration of muscle power by heavy resistance exercise. *J Bone Joint Surg*. 1945; 27: 645-667.
 30. Knight KL. Quadriceps strengthening with the DAPRE technique: case studies with neurological implications. *Med Sci Sports Exerc*. 1985; 17(6): 646-650.
 31. Holten Institute. www.holteninstitute.com. Downloaded 3/26/2009.
 32. Neitzel JA, Kernozeck TW, Davies GJ. Loading response following anterior cruciate ligament reconstruction during the parallel squat exercise. *Clin Biomech*. 2002; 17(7): 551-4.
 33. Kilduff LP, Bevan HR, Kingsley MIC, et al. Postactivation potentiation in professional rugby players: optimal recovery. *J Strength Cond Res*. 2007; 21: 1134-38.
 34. Goosen ER, Sale DG. Effect of postactivation potentiation on dynamic knee extension performance. *Eur J Appl Physiol*. 2000; 83: 524-30.